

Course Description

This course is designed to acquaint the student with the theory and applications of psychophysics and acoustics from the broad viewpoint of cybernetics. Concepts drawn from electrical engineering, psychology, statistics, decision theory and ergonomics will be integrated throughout the course presentation. Major study topics will include human decision making and modeling under uncertainty, psychophysical methods and experimental design, subjective measurement scales and probability assessment, auditory response theory and models, man/computer interaction using speech and a comparison of auditory with visual-tactile response phenomena. Some additional topics will include vigilance and feedback mechanisms as related to psychophysics. The course material will be motivated with practical applications and will contain a review of the required mathematical background.

Course Prerequisites

A course in probability theory is desirable.

Instructors

The course will be taught by [] with assistance from Dr. Edgar M. Johnson of the U. S. Army Behavior and Systems Research Laboratory.

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PSYCHOPHYSICS & ACOUSTICS - Lecture Topics

Introduction and Review of Probability Theory

Relative Frequency, Random Variables, Probability Distributions, Conditional Probabilities, Probability Laws, Averages, Variances, General Moments, Transformations of Random Variables, Distribution Types

Review of Random Time Events and Measurement Theory

Concept of Random Signals and Noise, Representations of Noise and Noise Types (visual, aural, etc.), Averages, Correlation, Spectral Concepts and Analysis, Filters, Bandwidths, Measurement Scales and their Establishment

Introduction to Decision Analysis

Problem Formulation, Decision Trees, Ideal Observers, Performance Criteria, Bayesian Analysis, Likelihood Ratio, Data Processing, Neyman Pearson, Min-Max, Thresholds, ROC curves, Regression Analysis

Methods of Psychophysics and Experimental Design

Binary Choice, Forced Choice and Free Choice Approaches, Stimuli Independent of Response, Stimuli Dependent on Response, Multiple Thresholds, Factor Analysis, Analysis of Variance, Tests of Significance

Psychophysical Scales and Utility Analysis

Rating scales, log function, power function, metathetic versus prothetic scales

Interactive Decision Systems

Subjective Probability Assessment, PIP, POP, Sequential Analysis, Fold-back of Decision Trees, Matrix Formulations, Reliability, Data Cost, Learning Assessment, ESP Estimation, Information Flow

Auditory Responses I

Cochlear Mechanics and Models, Cochlear Processes,
Directionality, Intensity, Damage, Temporary Threshold
Shift, Critical Bands, Noise Abatement, Applications

Auditory Responses II

Periodicity Pitch, Time and Frequency Analysis, Masking,
Fatigue and Adaptation, Perception, Energy Models,
Applications

Man/Computer Interaction Using Speech

Recognition and Synthesis, Advantages/Disadvantages,
Talk-back, Speech Recognition, Applications

Visual-Tactile Responses

Tactile Perception, Hearing/Feel Model Analogies,
Visual/Auditory Comparisons

Additional Topics

Vigilance, Pattern Recognition, Deferred Decision
Approaches, Feedback Systems and Mechanisms

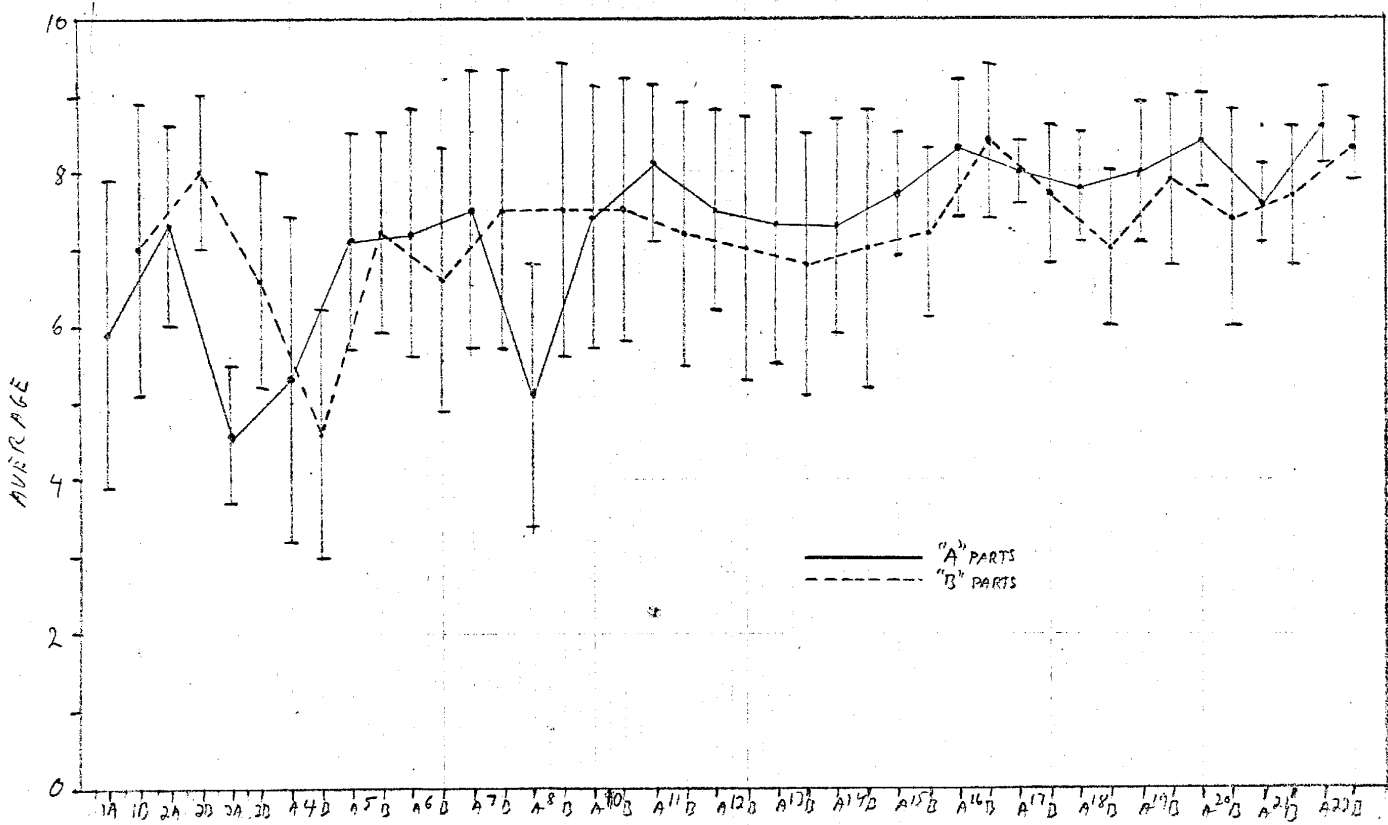
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It is proposed in this paper to deal with both the substance and the form of a pilot in-house course in Engineering Systems Analysis. In aerospace firms and in government*, it has been common management practice to configure working groups of engineers and scientists into large multidisciplinary arrays for projects. The term "matrix organization" is currently used to describe the pro-tempore mix of functional and management project personnel. By a process of iterative design between subsystems, it is possible to reach a set of project objectives set out for major engineering systems. Through the method of repetitive design, the team homes-in on a solution which is perhaps not ideal for any one subsystem but which is presumably ideal or optimum for a totality of subsystems, or for "the system." The process of examination of the system may be entitled Engineering Systems Analysis.

It is almost impossible for any one project manager to achieve intrinsic mastery of the many disciplines represented on his team. However it is possible for a generalized approach to be structured in this area. The application of statistical data analysis techniques is a promising vehicle wherein to frame a course sequence that will offer less than "all things to all men", but which will assist in the fundamental understanding of system performance.

The specific problem to be addressed by this type of course is that of tying together the information processing discipline, if it can so be called, as modified for multiple subsystems. In this discipline there has been a remarkable transition over the past 5 years at the practical level in both industry and government. A typical scientist or engineer working in this field might have an advanced degree in either mathematics, computer operations, electrical engineering or in experimental psychology. It is an interesting point to note that statistical processing has evolved from the convergence of three main fields. Each of these had developed its own symbology, techniques and problem-solving rationale from 3 fairly independent sources. These sources have been mathematics, experimental psychology and electrical engineering. Typically a small cadre of these types of problem-solvers are found throughout technical groups. The premise is made that strengthening and training potential members of these cadres will result in a better technical product.

An in-plant course sequence seems to hold promise for teaching effectiveness since the course design may be tailored directly to suit local "cultural" factors. A visceral set of quick feedback loops exists within the organization to correct the course

*represented by such firms as General Dynamics, TRW Systems and the U.S. Navy, where authors have had working experience. Project groups of 10-300 within a total organization of 200-1000 professionals are not uncommon.

both in material and in presentation. Esoteric material by its limited application may be sacrificed. Perhaps a background review of some of the current literature would be useful. The report here will discuss the design for a course format first and then will discuss the sequence of material proposed.

CURRENT CHALLENGE

After a decade of warm acceptance, both the value and the concept of "systems engineering" practices are being questioned today. Representative of this current challenge is an article by Secretary Robert Frosch¹ which urges that more engineering judgement be factored into methodology. To paraphrase the article, a rote practice of systems engineering has led downhill to an overemphasis on supportive impedimenta such as: configuration management, reliability, PERT and milestone schedules, complete logistics and programming tools for the operation of a vehicle (system) which has not undergone proper engineering design. In the process, those crucial core technical factors have competed at a disadvantage with systems priorities. This must change for the emerging systems of the future. The iterative and substantive character of engineering systems design has been somewhat overlooked.

The notion of an interdependent set of major subsystems being engineered artfully into a harmonious whole, is not all new or invalid. The early marriage of the gangplank to the trireme around 250 B.C. by the Romans is one early example of good subsystem compatibility. Frosch's point is that an overdose of current usage of systems engineering has tended to take away some of the essence of good practice. Chestnut² gives a series of major precepts which are basic to the systems approach. In these precepts the thought is central that it is quicker and cheaper in most designs to generate a small-scale math model or system simulation. From the model all of the design requirements of performance, component perturbation, sensitivity analysis, parametric variation and error budgets may be gauged better.

MODEL SYNTHESIS

Some form of model is therefore vital to the systems approach. The model can give dynamics for the various subsystems operating separately or together in orchestration. Interfaces between functions can be studied readily. In tune with current attention to ecology, Draper³ recommends that the logical solution here is to add on environmental design factors as another subsystem. He states that the advantage of a systems model in all fields is that it seems to offer a unitary approach to the attack on complex, interactive problems. New designs of surface vessels, aircraft, spacecraft and submersibles among others have required that large sets of mixed disciplines be grouped together, and this in turn has called for a new approach to technical management.

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Since the government has been a prime customer for major engineering systems, there has emerged a standard doctrine for "Phased Project" management and for "System/Project Management," terms used by NASA and DoD respectively. "There has always been a shortage of persons who can conceive, design and develop the complex systems demanded by the new technologies".⁴ Former trends have of late been overtaken by events in that the centralized role of systems analysis is less in focus than it was five years ago.¹ There is recognition of a need for better balance between the technical problem-solving role, judgemental engineering decisions, together with those standard procedures and quantitative decision-making tools associated with project management.

COMMONALITIES

A group of common tools can be identified which are pertinent to many hardware systems models; This set of tools may be stretched to accommodate to several major disciplines. These major fields would include optics, acoustics, electromagnetics, seismics as well as parts of human engineering and biomedicine. If leading publications of these fields are culled, a pattern of commonality in the mathematical modelling may be noted to exist beneath the semantic language of the particular field. This would imply that if symbology and approach were systematized for a set of applications, then complex sets of problems in individual technical fields would be tractable to a more catholic approach. Examples are found in transformations, matrix manipulations, numerical methods, statistics and probability, etc. Beyond these basic tools, there is a set of subsystems commonly used in systems design for all of these disciplines. Common subsystems are detection and decision-making functions, spatial or multisensor processing, control subsystems and servomechanisms, modulation codings, and others.

PROBLEM SOLVING AND HUMAN FACTORS

There is evidence that internal problem-solving within the organization would improve in quality by providing technical people with a multi-field set of tools.² Frishmuth and Allen propose a model for the technical problem-solving process. They noted that the engineer employed on a problem, rapidly becomes insensitive to acceptance of new alternatives as he becomes positively biased toward a particular technical approach. He thus develops a higher threshold as soon as confirming information is received for a particular route to problem solution. "Openness to additional cues is drastically reduced and is either normalized or gated out." It would follow that the basic solution approach would be enhanced by providing the worker with the ability to translate between fields of technology. The reason for this would be that a wider range of technical alternatives are made available as analogs at the beginning of the problem-solving process. Examples of coherent processing for instance thread

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through all fields of physical and life sciences in signal analysis. Modulation schemes offer another example.

Further data on the problem-solving mechanism were developed by Allen and Marquis⁶. Their controlled experiment covered 5 laboratories working on the identical problem, and 3 separate laboratories working on a second problem. Conclusions of the study were that prior knowledge or experience with techniques appropriate to the problem, generally resulted in a positive bias regarding the solution. The converse was also true to result in a negative bias to successful solution. For the negative bias case, where a second alternative was considered, the probability of success was raised from zero to a half.

The effects of training and experience on technological transfer is discussed by Gruber and Marquis.⁷ Internal sources in a total organization were more effective for technical transfer in contrast to reliance upon outside consultants or upon externally contracted research. This study also found the productive years for an engineer as between 34 and 40.

Regarding attitudes towards continuing education, a recent NSPE (National Society of Professional Engineers) survey⁸ showed that of 2,500 respondents, about 55% had taken programs of continuing education. Of the 2,500, 41% had been motivated by the hope of further professional advancement. Continuing educational studies outside advanced degree programs were seen as a requirement by ASME to be met by the profession and by academic institutes. "It is a matter of taking a long range look at the ever increasing rate of technological change and then deciding what now needs to be done to assure that continuing effectiveness of the profession in the 1970's and beyond."

The advanced degree program was studied by Ruben and Morgan.⁹ Supplementary training was pursued in an inverse proportion to the formal educational attainment for the group studied. The higher the degree, the less likelihood of participation in supplemental training. The problems of motivation were studied. A group of 370 engineers and scientists at the Langley NASA Research Center were polled. Control groups were:

- (a) Those who received the MS degree version of the test questionnaire.
- (b) Those who received the 7-courses version.
- (c) Those who received the 1-course version.

The test procedure was a rating of individuals on a semantic-differential scale; the scale consisted of 15 adjective-pairs, rated from 1 through 7. Typical pairs related to perception of an individual such as: scientific or non-scientific; poised or awkward; aggressive or timid; high initiative or low initiative; etc.

The results of this test showed that there was little perceived difference in performance between the MS group and the 7-courses group. There was significant difference between the 1-course group and the others. Otherwise stated, the results were that individuals who had participated outside in over 7 courses were perceived as preventing technical obsolescence in themselves; the outside effort was perceived as a route to organizational advancement.

TIME ALLOCATION OF TECHNICAL SUPERVISORS

For an effective in-house program it is relevant to examine the relative amounts of time allotted under pressure by the technical supervisor. This is highly meaningful because 10 for sustained attendance one must have the backing of the supervisor. The effort of the individual in the course is influenced by his perception of how his superior is linked with the organization and how that supervisor wishes him to allocate his own training effort. One technical organization in DoD, of about 800 technical personnel, showed that first-line supervisors (57) felt that a 15% time allotment was average for "advising and training" subordinates. For second line supervisors, (24) a 10% allocation was given. For laboratory managers, the highest level in the organizational hierarchy, (8) an allotment of 11% was cited. For continuing training by itself, an allocation of 9:5:5 per centage respectively was observed.

AGING ORGANIZATIONS

The problem of aging technical organizations is discussed 11 by Edward Roberts, based upon his "Research on Research" studies at the Sloan School of Management. Roberts deals with government RD&E centers with different mixes of technical and support people. He suggests that the "head limitation" extant now in all government groups, results in degenerative production. He states that "growth limitations whether by directly restricting the budget or by setting a head count limit on the number of employees can be critical (debilitative) factors in all R&D organizational dynamics." This particular point may prove to be unrealistic. He indicates that corporate management, i.e. senior government management in an Agency, can provide measures realistically addressing continuing employee education to offset this decline in technical effectiveness.

COURSE DESIGN

A nominal 5% was felt to be a practical time commitment for the course. A positive reinforcement was felt to be visible in allotting 1 day per 4 weeks for a full day seminar session. It was attempted to have this day fall on the same day of the week and the same week each month. It was attempted to provide consistency in classrooms, format and class notes. Continuing contact between sessions was designed to be maintained via several means. Home problems, detailed handouts from the problem solutions conversations through the month with both students and group leaders

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special handouts and reprints of technical literature were made to maintain a continuing contact. An intermediate 2-hour problem solving session was held midway between the full-day sessions. Additionally, a visible response was attempted to any suggestions or interactions by the students or their supervisors. The full-day session was arranged in a round table format; a class note packet was received by each student approximately 5 days prior to the session. A chalk board development was intentionally made in a pictorial formulation by the instructor. Morning periods were intended to cover basic development of the particular topical area and to delve into the system theory pertinent to the particular subject. The early afternoon period was used for a detailed in-house application example; a high degree of relevance was possible here by working with the "guest" lecturers about 2 weeks in advance. The late afternoon period consisted of a second-level approach to the earlier base material. This was intended to allow for heterogeneity the student background and interest.

POLL FOR ESTABLISHING CONTENT

As an initial step in framing the substance of the course, a questionnaire was circulated to a representative government group. Comments were asked on preferred timing and on background; the main thrust of the poll however was to indicated areas of perceived strengths and weakness in a set of 12 topical groups. Table I lists the 12 areas and the indicators¹² for each, which were framed using the Miller listing. The actual list cited in this reference were paraphrased and modified somewhat to accommodate to general system needs. Where a respondent singled out an area as a weak personal point or as a strength, in a definitive way on the returned questionnaire, the count was accrued. A profile of internally perceived competence may be inferred from the cumulative data. This in turn was used to frame the content of the course. There is no correlation with respondents and the numbers of strengths or weaknesses cited, since overlapping subsets are present. However, it was felt that a relativemix of about 50% "subsystems" would be appropriate following a 50% time allocation to the more basic building blocks. Table II lists the total distribution of degrees. The four non-degree respondents had more than 2 years of college in technical fields; the advanced degrees shown usually were for respondents who had also achieved earlier prerequisite degrees. (No professional degrees were noted.) It had been expected that the interested group would be diverse both in level and in field.

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